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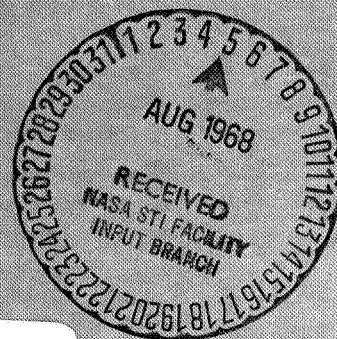
Final Report  
on  
FABRICATION OF THERMAL COATED EXTENDABLE BOOM

Contract No. NAS 5-10130

20 March 1968

Prepared by  
WESTINGHOUSE DEFENSE AND SPACE CENTER  
Aerospace Division  
Baltimore, Maryland

for  
GODDARD SPACE FLIGHT CENTER  
Greenbelt, Maryland



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## SUMMARY

This report documents the program established to develop a process for coating booms to be thermally stable in a space environment as required for the Application Technology Satellite (ATS). The coatings developed were vacuum deposited aluminum for the outside and jet-black cupric oxide for the inside surfaces. Both of these coating processes were designed to be compatible with the previously developed technique of chemically milling windows in the tape.

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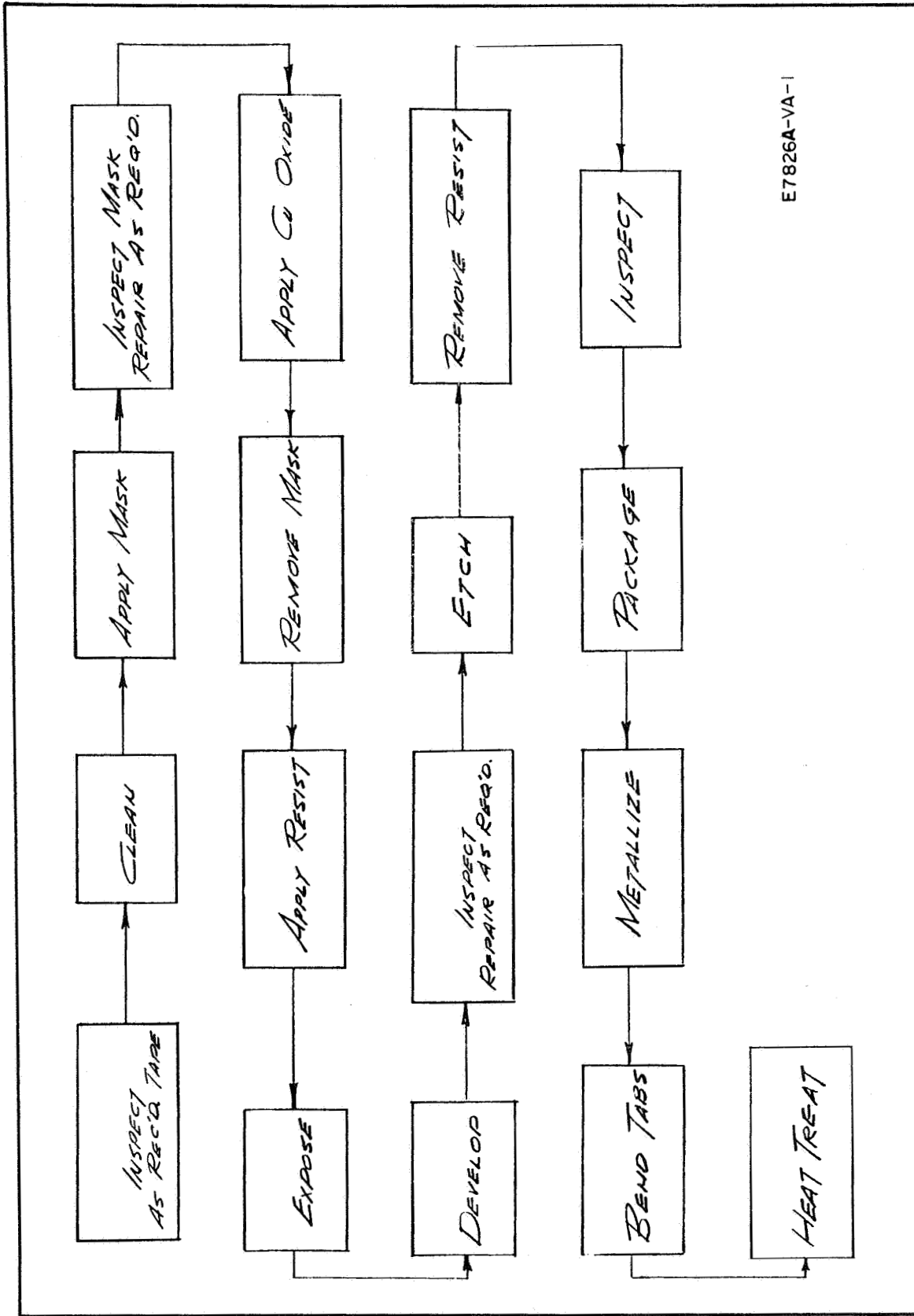
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## 1. INTRODUCTION

The objective of this program was to develop a process for coating booms with an  $\alpha$  ratio of approximately 6:1 between internal and external absorptivities as required for the Application Technology Satellite (ATS) development contract. Efforts were taken to minimize the total heat absorbed by having the absorptivity of the outer surface as low as practical. The combination developed was vacuum-deposited aluminum on the outside and Ebonol "C" on the inside.

The process flow is shown in figure 1. The BeCu strips purchased from Hamilton Watch Company, Reading, Pennsylvania, are received in a 1/2 hard condition. After inspection and cleaning, they are masked on one side for development of the black oxide on the exposed surface. The mask is then removed and a photomask applied for chemical milling of the window pattern. After milling, the mask is removed and tape is prepared for metallizing. Tabs are then bent and tape is finally heat formed into the shape of a boom.



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Figure 1. Flow Diagram - Extendable Boom Fabrication



## 2. EBONOL "C" PROCESS

### 2.1 CLEANING OF RAW MATERIAL

The cleaning of No. 25 beryllium copper alloy strip, as developed under Contract No. NAS 5-10130, consisted of immersion in Nutra-Clean<sup>1</sup> followed by rinsing in tap water. Residual water on tape was dried by natural evaporation. This process proved satisfactory for the purpose intended, namely, to provide a surface clean enough to accept photoresist. For this program, however, improvements in cleaning techniques were found necessary because surface conditions for adhesion of vacuum-deposited aluminum coatings proved to be more demanding.

Our experiments disclosed that failures experienced with the proprietary cleaners were essentially due to their alkali content, which was difficult to remove effectively. For this reason, an organic solvent process was developed which resulted in significant improvements in adhesion, because the residue which may have remained did not react unfavorably like the alkali.

The initial organic process consisted of passing the tape through three tanks of M-17.<sup>1</sup> Neither water rinses nor air squeegees were found necessary. In the interest of economy, the solutions were cycled with each production run from tank to tank, keeping clean solution in the final tank. Upon placing a commercial vapor degreaser with trichloroethylene on line, the M-17 line was discontinued. The standard speed in the degreaser was 4 fpm. As the tape was passed through the spray zone, both surfaces were scrubbed with rotating nylon brushes. A schematic of the vapor degreaser is shown in figure 2.

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1. Supplied by Shipley Company, Los Angeles 28, California.

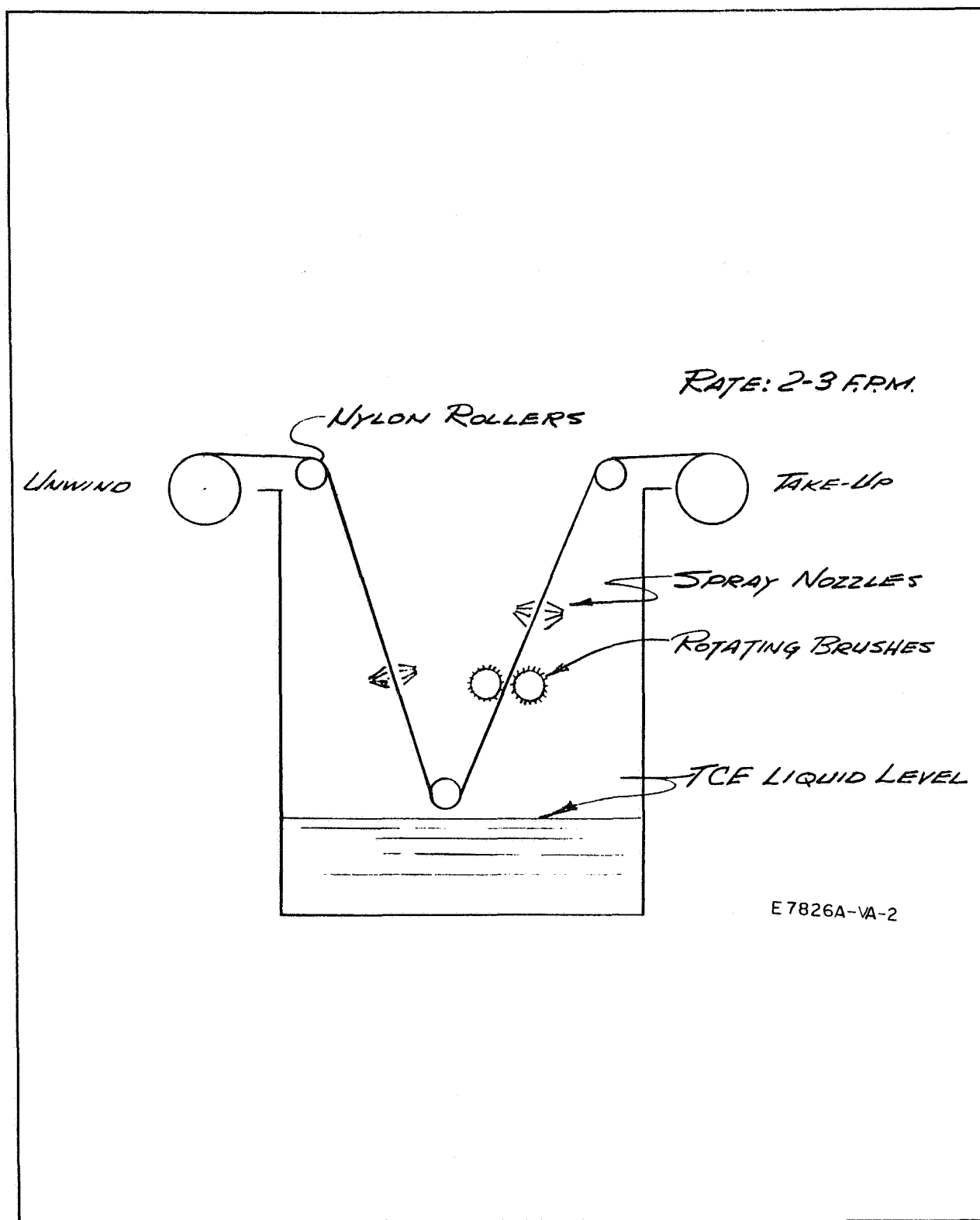


Figure 2. Schematic Diagram of the Vapor Degreaser

## 2.2 APPLICATION OF MASKING LACQUER

### 2.2.1 Background

In the course of developing the existing process, attempts were made to apply stop-off lacquer by spraying, brushing, and rolling. The results were unsatisfactory because coating thickness could not be controlled and lacquer flowed to the reverse side of the tape.

### 2.2.2 Existing Process

The existing process employs the use of a "Kiss-Coater." Experiments were performed in conjunction with this device to select coating thickness and curing temperature. From these experiments, it was determined that two thin coats gave better coverage than one thick coat thus eliminating bare spots (pin-holing) in the coating. Variations in curing temperature had a minimum effect if the temperature were held within the range of 115 to 130°F.

Miccroshield<sup>2</sup> stop-off lacquer, thinned with Miccroshield Reducer,<sup>2</sup> was used in the existing process. The lacquer was adjusted, by addition of the reducer, to a viscosity reading of 31 to 33 seconds using a No. 1 Zahn cup measured at 70 ±5°F.

The BeCu tape was placed in the "Kiss Coater" (figure 3) in such a manner that the side of the tape to be coated just contacted and was level with the surface of the lacquer. The liquid level was adjusted, by the level controller giving the tape maximum immersion without causing spillage on the side not intended to be coated.

The lacquer coating was thoroughly dried using radiant heaters before being reeled. Drying was accomplished by passing the tape through a heating zone with heaters on either side of the tape. The air at the tape surface was held within the temperature range of 115 to 130°F as measured at the center of the heating zone. As the tape was reeled after "Kiss Coating," tissue paper was interwrapped to protect the coating on the processing reel. The

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2. Supplied by Michigan Chrome and Chemical Company, Detroit, Michigan.

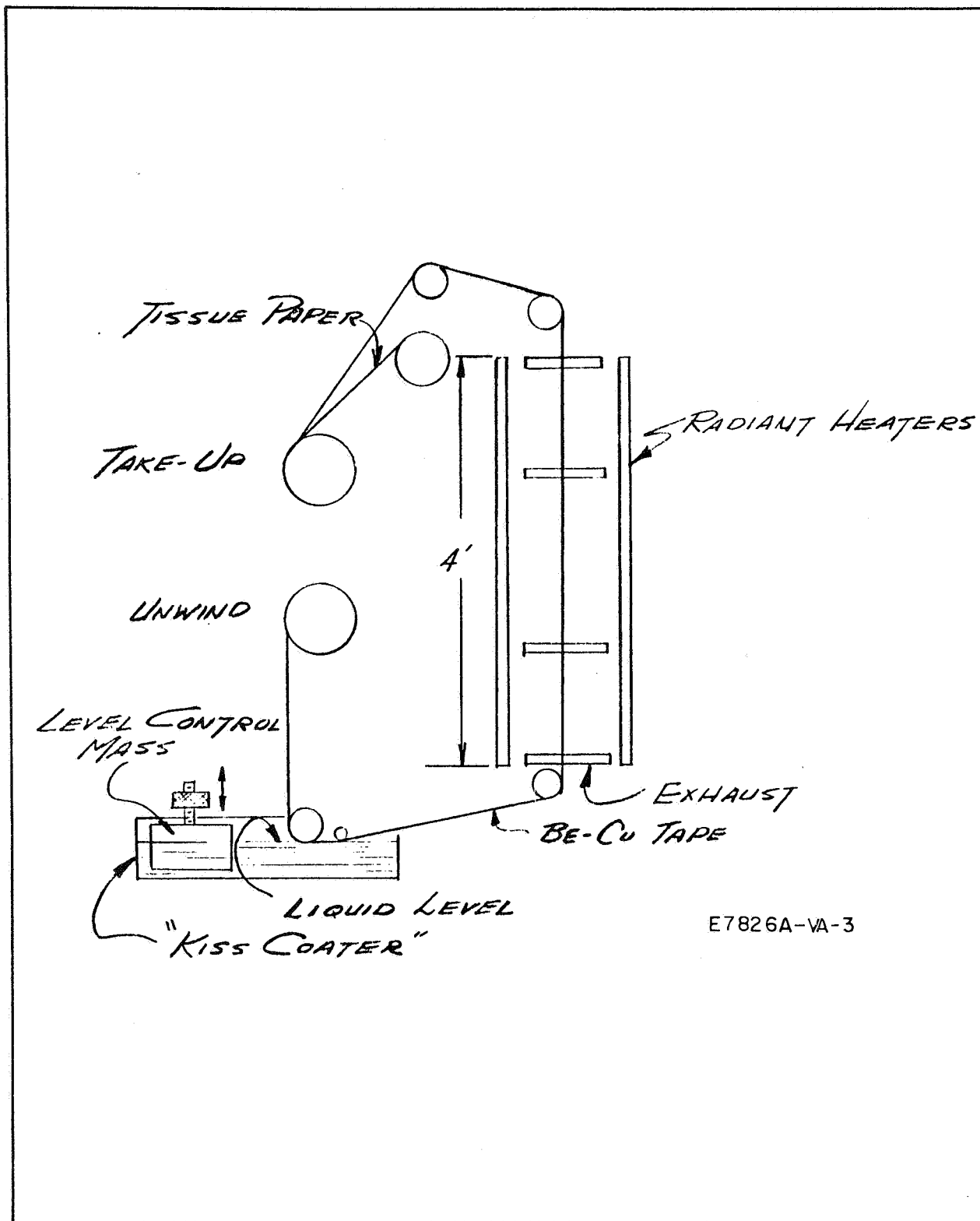


Figure 3. Schematic Diagram of Existing Method of Applying Masking Lacquer

tape was continuously drawn through the "Kiss Coater" and drying zone at a rate of 15 to 18 in/min. Two complete cycles were required.

## 2.3 DEVELOPMENT OF COPPER OXIDE PROCESS

### 2.3.1 Background

The process developed for the inner surface of the boom was a modification of a proprietary process known as Ebonol "C,"<sup>3</sup> which produced a jet-black cupric oxide coating. Most of the problems arose because of the beryllium content of the alloy. The beryllium sites on the surface presented a situation very analogous to pit corrosion, thus resulting in discolored spots. The initial investigation was started with the commercial process as a batch process, making those improvements deemed necessary as the investigation was continued. Various descalers, cleaning solutions, times, and temperatures preceded the selection of the continuous Ebonol "C" process now employed. Typical of processes investigated was the following procedure:

- a. Clean by immersion for 2 to 5 minutes in alkaline cleaner, Enthone<sup>3</sup> S-61. Temperature: 180 to 212°F.
- b. Hot water rinse.
- c. Immerse in a hot (180 to 212°F) solution containing 1.5 lb/gal of Enthone<sup>3</sup> 2-A activator for approximately 5 minutes.
- d. Hot water rinse.
- e. Immerse in hot (180 to 212°F) Ebonol "C" solution containing 1.5 lb/gal for 10 to 15 minutes.
- f. Hot water rinse and air dry.
- g. Wet polish.

The above method was unsatisfactory because a nonuniform cupric oxide coating, light to dark brown in color was developed but it did indicate a promising direction.

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3. Supplied by Enthone, Inc., New Haven 2, Connecticut.

### 2.3.2 ORBIT<sup>4</sup> Process Investigation

ORBIT was investigated for a backup. In their process, copper was first electroplated over the tape and this pure copper coating was subsequently converted to black oxide. Their results were black but nonuniform and a pattern of marks were present, presumably due to a mechanical brush used for cleaning the tape surface. In our opinion, their process was not developed far enough to justify continued support.

### 2.3.3 Existing Copper Oxide Process

The existing process was developed experimentally by studying the effect of various permutations of temperature, concentration of solutions, and time of immersion. The procedure finally adopted was as follows:

- a. Chemical Pickling Activation - Clean by immersion for 2 to 3 minutes in a solution of 12 oz Actane<sup>5</sup> 97, 9 oz Actane 97A and 3 oz Actane 70 dissolved in 10 gallons of water. Temperature ambient.
- b. Spray rinse thoroughly using cold tap water.
- c. Copper Oxide Ebonol "C" - Immerse for 2 to 3 minutes in solution of 2 to 3 lb/gal Ebonol "C" at temperature of 210 to 220°F; specific gravity 1.22 to 1.45 measured with solution at 70 ±5°F.
- d. Spray rinse thoroughly using cold tap water. Midway through the water rinse, use an acid rinse of one-half of a percent by volume of sulfuric acid to neutralize the surface.
- e. Air dry with filtered compressed air.
- f. Buff the copper oxide coating to remove any loose deposit and to lay down the nap characteristic of the coating when initially produced.
- g. Inspect for jet black appearance, free of discontinuities and reverse side free of any evidence of black oxide.

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4. ORBIT Electroplating Co., Bloomfield, New Jersey.

5. Supplied by Enthone, Inc., New Haven 2, Connecticut.

A schematic of the process equipment is shown in figure 4. A report on the compatibility of copper oxide in a space environment is included in Appendix I. From this report, it is concluded that the compound has a high thermal stability and a very low vapor pressure over the temperature range and pressure of concern for this application.

## 2.4 REMOVAL OF MASKING LACQUER

### 2.4.1 Background

The preliminary investigation of methods to remove masking lacquer from the BeCu tape included the use of solvents Microstrip "B"<sup>5</sup> and Furfasol solvent M-17.<sup>6</sup>

The tape was passed unreeled through one tank of Microstrip "B," spray water rinsed (cold tap water), followed by immersion in one tank of M-17. Microstrip "B" is a strong caustic solution which was later found difficult to remove from the tape surface. After the tapes were coated with aluminum, these residual salts caused the aluminum film to fail adherence tests. Upon installation of the vapor degreaser, this method was abandoned.

Initially the masking lacquer was removed by passing the unreeled tape through the spray zone and then through the vapor phase of the vapor degreaser containing trichloroethylene (TCE). This method was found to be unsatisfactory, because areas of residual masking lacquer, detrimental to the adhesion of the aluminum coating, persisted even after two to four passes through the vapor degreaser.

To determine effectiveness of other stripping methods, samples of tape were coated with masking lacquer (processed through the "Kiss Coater") and stripped. These samples, 6- to 8-inch long, were then admitted to a vacuum chamber, given a 5-minute glow discharge cleaning, followed by deposition of 400 Å of aluminum. The quality of the aluminum adhesion,

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6. Supplied by Michigan Chrome and Chemical Co., Detroit, Michigan.

7. Supplied by J.B. Moore Company, Nutley, New Jersey.

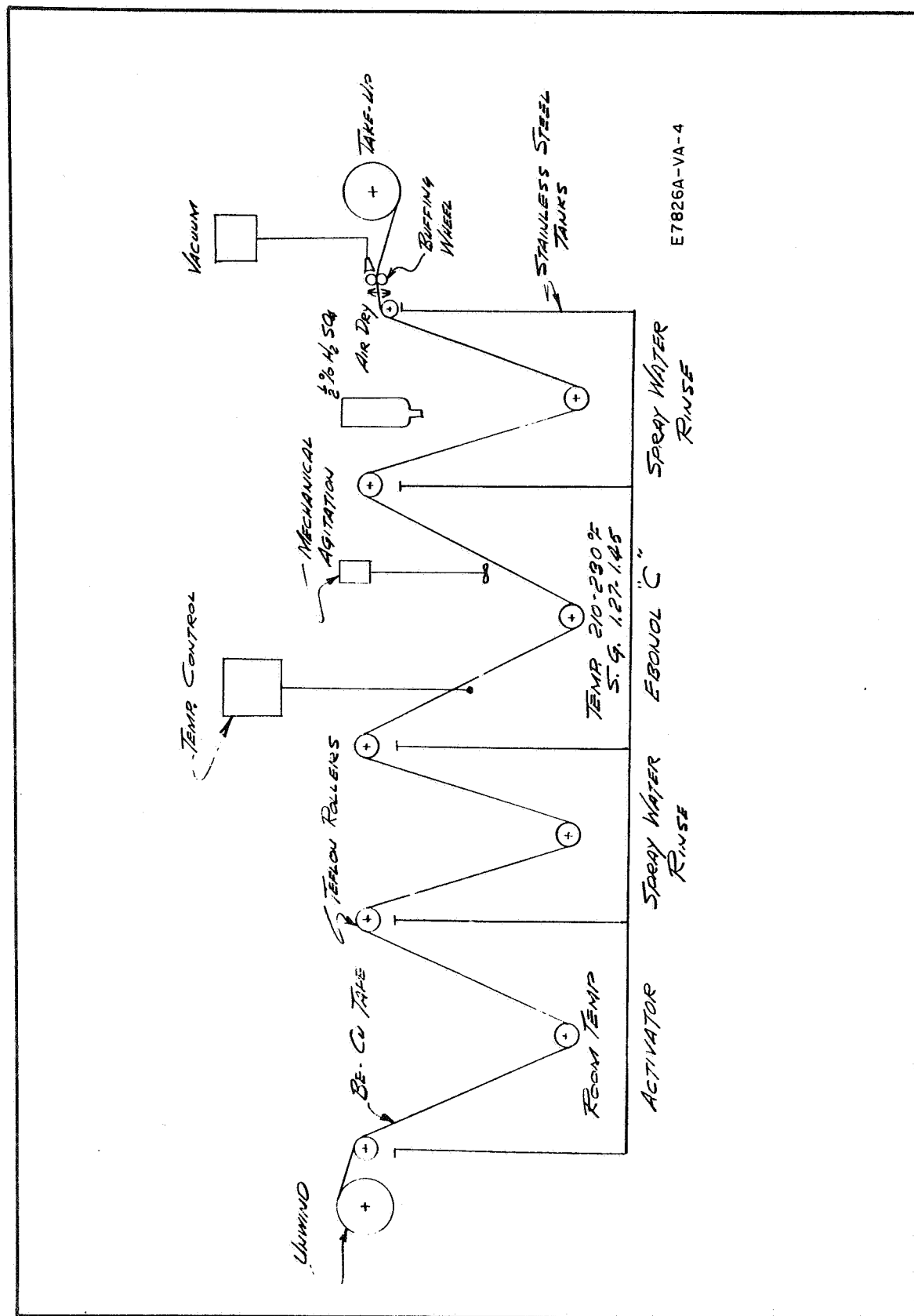


Figure 4. Schematic Diagram of Cupric Oxide - Ebonol "C" Process



as determined by the cellulose tape test, was used as a method of evaluating the effectiveness of the various mask removal experiments performed.

Following are several of these experiments:

- a. Control sample. As received BeCu tape and vapor degreased once.
- b. Stripped of mask (2 passes through vapor degreaser).
- c. Stripped of mask (3 passes through vapor degreaser).
- d. Stripped of mask (3 passes through vapor followed by acetone wipe).
- e. Stripped of mask (4 passes through vapor degreaser).
- f. Stripped of mask (2 passes through vapor degreaser followed by hand polish with 0.05  $\mu$ m alumina and isopropyl alcohol. Rinsed in deionized water. Dried in N<sub>2</sub>).
- g. Stripped of mask (2 passes through vapor degreaser followed by hand brushing in room temperature TCE).
- h. Stripped of mask (2 passes through vapor degreaser followed by hand polishing with metal polish. Rinse in TCE).
- i. Stripped of mask (2 passes through vapor degreaser followed by 15-minute heat in ambient air at 230°F).

#### 2.4.2 Results

In each experiment, a control sample (1) was vacuum coated along with the samples to be tested. This material served as a check on the condition of the vacuum chamber as well as a comparison with the test samples. With a properly operating, noncontaminated vacuum chamber, the control sample had 100-percent adhesion in all instances.

Consistent results on the samples other than the control sample could not be obtained. The aluminum adhesion ranged from 50 to 100 percent. However, it was noted that any mechanical action, i.e., brushing or wiping, hastened the mask removal and gave more consistent clean surfaces. These observations prompted the installation of rotary nylon bristle brushes in the vapor degreaser. Both sides of the tape are now continuously brushed as well as sprayed with clean pressurized TCE for more effective masking lacquer removal, and subsequent excellent adhesion of deposited aluminum.

### 3. PHOTOMASKING AND ETCHING

This process was not changed. The following paragraphs describe the procedure in use.

#### 3.1 APPLICATION OF RESIST

Resist preparation: Photoresist is mixed with thinner in proportions so as to get a No. 1 Zann cup reading of 27.5 sec to 28.5 sec at 70°F  $\pm$ 5°. This will require adding approximately 1 part of thinner to the 3 parts of resist.

#### 3.2 EXPOSURE

A photographic transparency of the hole pattern is exposed on the side opposite the black oxide coating. The tape is drawn through the exposure light source at 15 to 18 in/min.

#### 3.3 DEVELOPMENT OF MASK

Developing: The tape is unreeled through the developer with an immersion time of 1.5  $\pm$ 0.25 min, rinsed by a cold tap water spray, and dried with filtered compressed air.

#### 3.4 ETCHING PROCEDURE

The etchant was Ferric Chloride at 42° Baume maintained at 100  $\pm$ 10°F. The tape was passed through a commercial spray etcher, rinsed with tap water, and blown dry with filtered compressed air.

#### 3.5 PHOTORESIST REMOVAL

##### 3.5.1 Development

The investigation of methods to remove photoresist from the BeCu tape included the following:

a. The tape was continuously drawn through one tank of undiluted Al-Chelate,<sup>8</sup> rinsed in cold tap water and dried with compressed air. Salts from the Al-Chelate were difficult to remove from the tape as evidenced by a white residue adherent to the surface after rinsing.

b. An additional continuous process employed the use of three consecutive tanks of Furfasol solvent M-17, with an intermediate compressed air dry. The solvent was cycled from tank to tank keeping clean solution in the final and discarding the solution from the first tank. This procedure left a white residue, which was soluble in acetone, on the tape surface.

c. Numerous batch-type experiments, using a variety of organic solvents, were performed. Of the solvents tested, acetone was most effective in removing the resist.

#### 3.5.2 Existing Process

The existing process employs the use of three consecutive solvent tanks. The first tank contains commercial grade acetone, the second tank Furfasol M-17, and the final tank acetone.

Upon emerging from each tank of acetone, the tape is dried with filtered compressed air. After each 200-ft length of tape has been passed through the stripping tanks, the acetone in the first tank is discarded and replaced by the acetone in the final tank. The M-17 is replaced after 400 ft of tape have been stripped. Each tank contains approximately three gallons of solvent. The tape is drawn through the tanks at a rate of approximately 4 fpm.

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8. Supplied by Shipley, Inc., Los Angeles, 28, California.

## 4. METALLIZING PROCESS

### 4.1 DEVELOPMENT OF SUBCONTRACTOR

Since production facilities for vacuum strip coating were not available at Westinghouse, development of a subcontractor became necessary. Three sources were investigated:

- Catalyst Research, Towson, Maryland
- Schjeldahl, Northfield, Minnesota
- Temescal Metallurgical Corporation, Berkeley, California

### 4.2 DESCRIPTION OF FACILITIES

#### 4.2.1 Catalyst Research and Schjeldahl

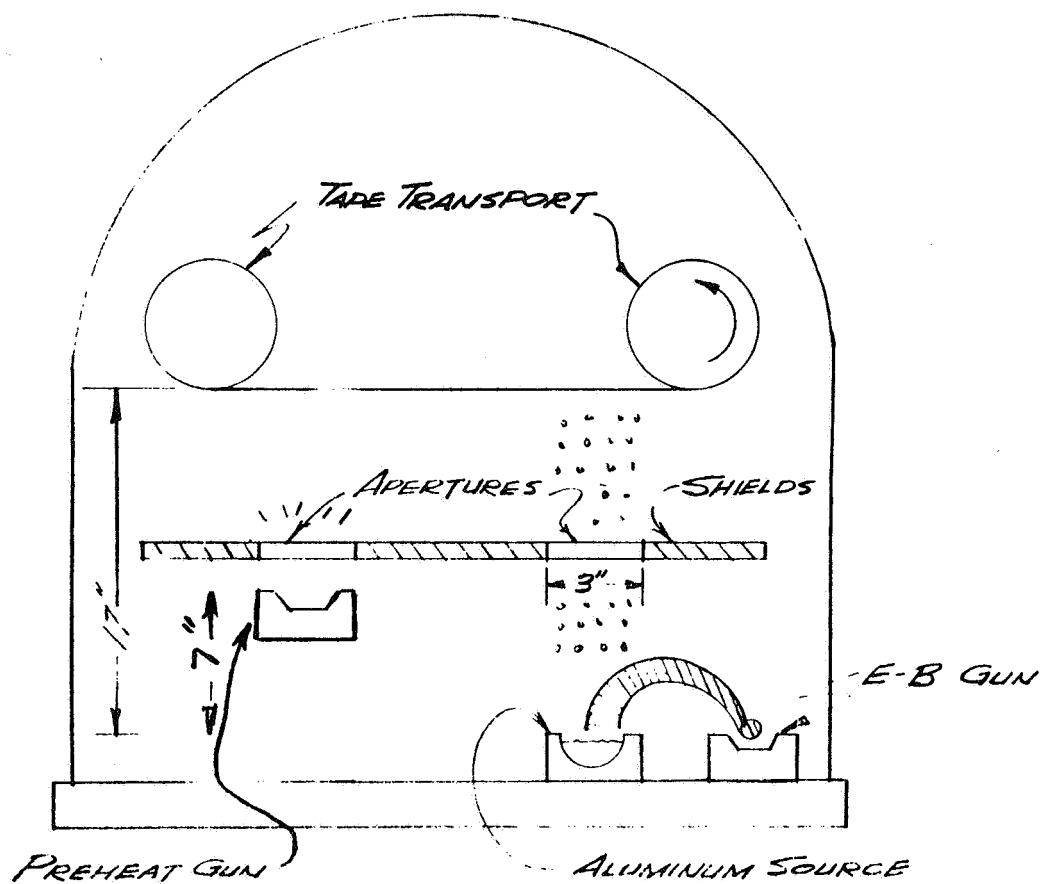
Catalyst Research and Schjeldahl used equipment very similar in nature. In their processes, the tape was supported on a drum, and the drum was rotated past a bank of tungsten filaments located on the bottom of the chamber. Aluminum staples attached to the filaments were used as a metallizing source. Both used glow-discharge cleaning prior to coating.

#### 4.2.2 Temescal Metallurgical Corporation

In contrast to the above, the Temescal process was quite different (figure 5). A tape transport system was used in lieu of a drum. Between the span of the rollers were located two electron beam guns on the base plate. The first gun supplied thermal energy for cleaning; the second gun was used as a source of energy to melt aluminum contained in a crucible. A sketch is shown in figure 5.

### 4.3 SUBCONTRACTOR SELECTION

On the basis of performance, as judged by reflectivity data, the Temescal process was selected over the others. The difference in reflectivity was significant. A secondary reason for the decision was availability of facilities.



E7826A-VA-5

Figure 5. The Temescal Metallurgical Corporation's Coating Process

Temescal was found to be very cooperative in scheduling their facilities at our convenience.

#### 4.4 PROBLEM AREAS

The primary objective was one of developing an optimum technique for satisfactory adhesion. The conventional scotch tape test was considered as the criterion for evaluation. The problem areas were:

- Strip cleaning equipment not available at Temescal.
- Temescal process not designed for BeCu.

##### 4.4.1 Development of Cleaning Process

Since the subcontractor did not have strip cleaning equipment, Westinghouse was faced with the problem of developing a cleaning process for coating. Among the difficulties experienced, probably the most critical was the inability to establish a foolproof test for evaluation of tape for the Temescal process. In most cases, the batch test run at Westinghouse resulted in better adhesion than the production process.

The solution to the problem was accomplished by a heuristic method. Satisfactory adhesion had been obtained with strip cleaned and coated at Catalyst. With this knowledge at hand, each step in the process was evaluated using the Catalyst process as the control. Through a process of elimination, the sources of contamination were revealed and appropriate action taken. Discussion of more detail were given in paragraphs 2.1 and 2.4.2.

##### 4.4.2 Solution to Metallurgy Problem

The second problem was related to the metallurgy of BeCu. Because of the aging characteristic of the alloy, the outgassing technique used at Temescal for their product line was considered detrimental to the ultimate mechanical properties. This technique, consisting of heating above 500°C in vacuum, was sufficient to age the alloy significantly. This phenomena is equivalent to impressing an undesirable memory in the tape to remain flat and, therefore, resist subsequent techniques for forming a cylindrical form.

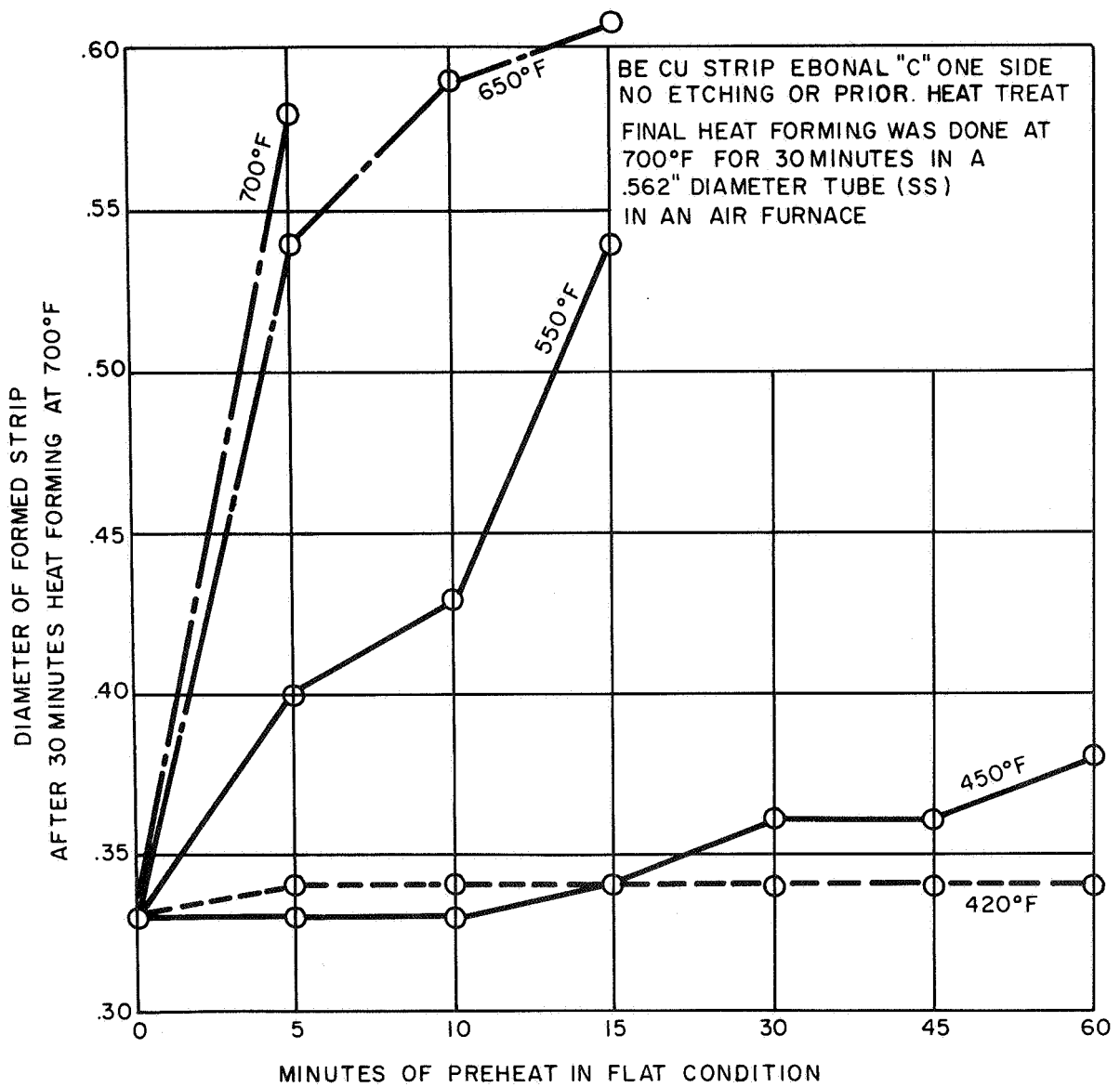
Initially, tapes were coated with no preheat. This decision proved to be too conservative as evidenced by a complete lack of adhesion of coating. In order to overcome this problem, a metallurgical investigation was conducted to determine the maximum temperature that the strip could tolerate without any significant evidence of aging.

A procedure was established to simulate the dynamic conditions of processing. Sample strips of BeCu with Ebonol "C" on one side were preheated at various temperatures and times in a flat shape. Subsequently, they were formed at 700°F for 30 minutes in a 0.562-in tube. The results, as shown in figure 6, indicated that there was no significant effect of aging detected at 420°F for 60 minutes. On the other hand, dramatic evidence of aging was shown for the higher temperatures.

A check was run on this experiment by comparing a tape with no preheat with tapes exposed to up to three preheats. Results in figure 7 were in conflict with the original conclusion.

One explanation offered for the discrepancy was the possibility that the tape without preheat was not the same as the other samples with respect to response to heat treatment because the coincidence of the other curves was so remarkably close. A special test was subsequently run in which all the permutations were included on the same strip so that it had a built-in control. Results shown in figure 8 vindicated the original conclusion by the evidence of coincidence of preheat curves and aluminized curve.

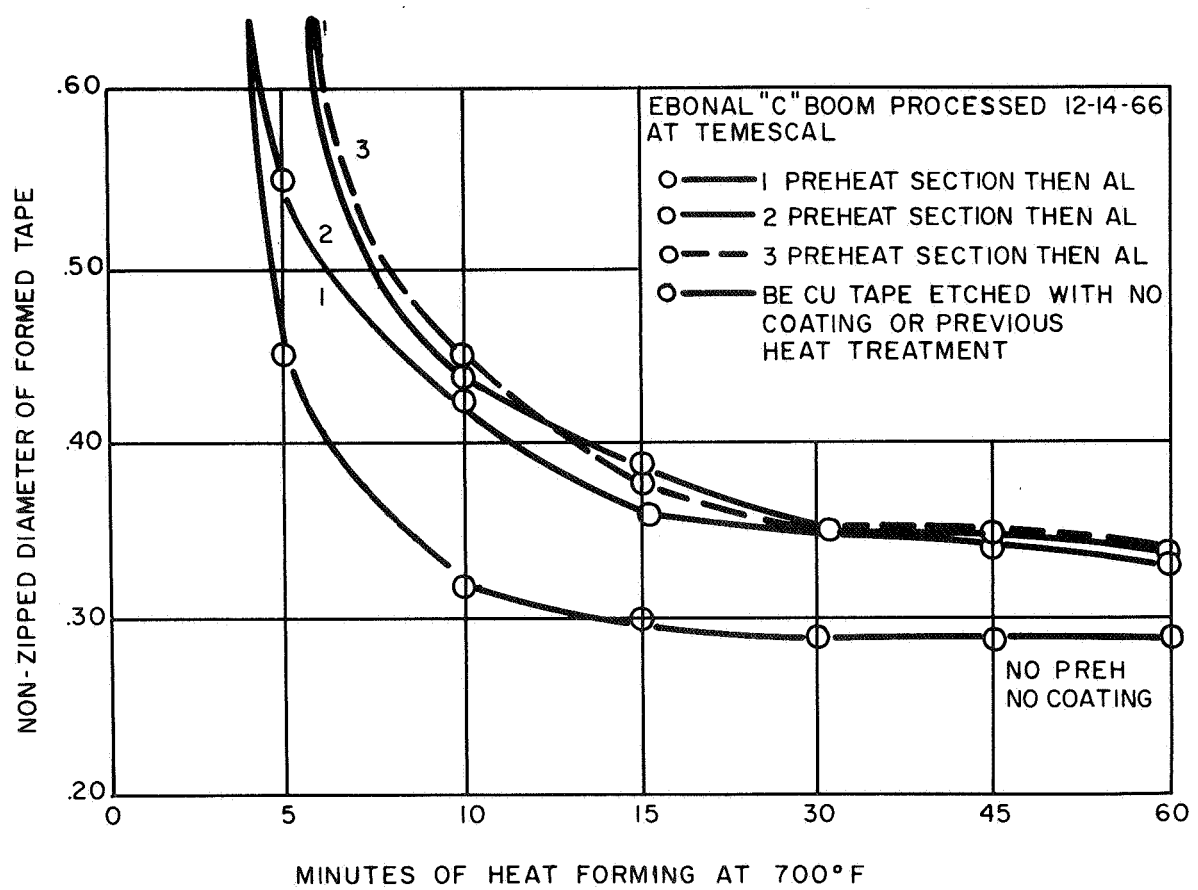
The curve which is not coincident was considered a special case, because the tape was coated with aluminum oxide on the opposite side thus incurring much more heat. Evidence of a larger free diameter, verified this conclusion. An examination made of some of the older tape in our inventory also confirmed the conclusion that response to heat treatment was different in some cases. A conclusion was reached as a result of these tests that 420°F was a safe temperature for preheat in the Temescal process.



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Figure 6. Effect of Preheat in Flat Condition on Forming





7484A-VB-2

Figure 7. Effect of Preheat in Flat Condition on Forming

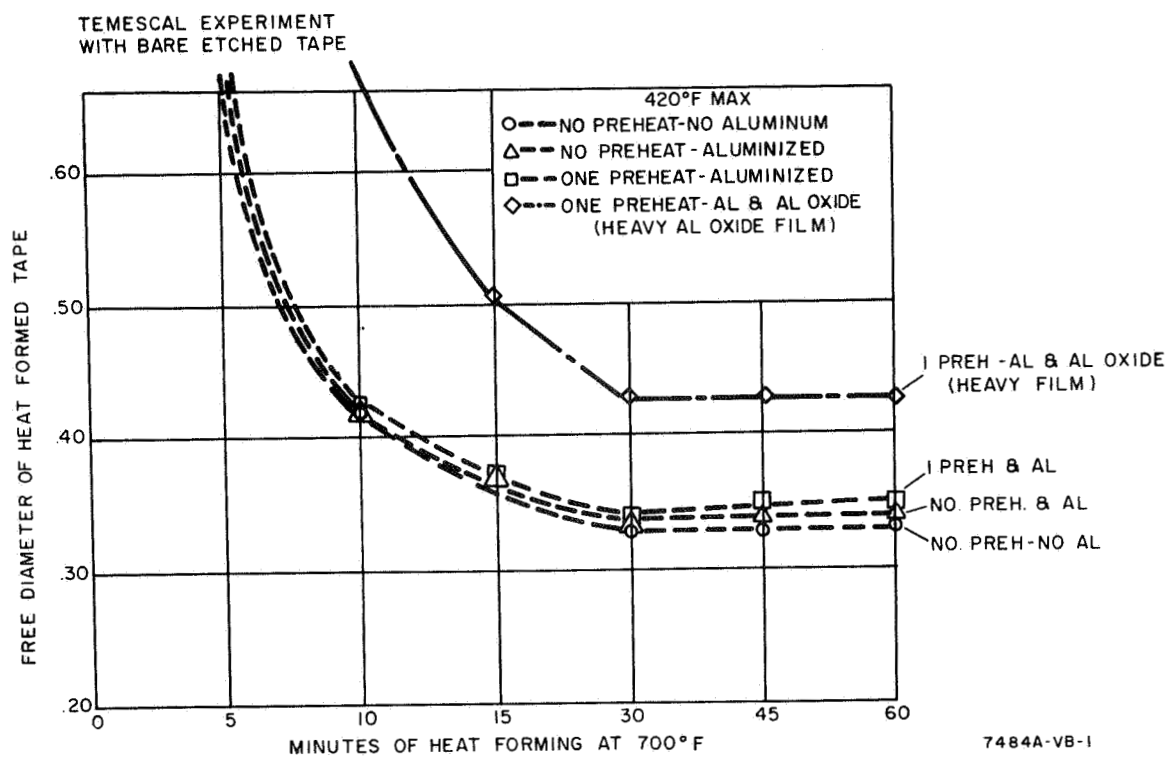


Figure 8. Final Preheat Experiment Run at Temescal

#### 4.5 COATING PROCESS

The mechanical setup used was their standard operating procedure. As shown in figure 5, the preheat gun and aluminum gun were located 10 inches and 17 inches, respectively, from the tape.

The tape was driven at nominally 15 fpm. Preheat temperature was set at 420°F maximum. Evaporation was started at nominally  $3 \times 10^{-4}$  torr and pressure decreased gradually to  $10^{-5}$  torr during coating.

At the beginning of the process development, several preheat passes were required for adhesion. As the cleaning process was improved, the need for extra preheat became unnecessary. After coating, the tape was packed in a moisture-proof package with desiccant for shipment by air to Westinghouse.

## 5. BOOM FORMING

### 5.1 METALLURGICAL INVESTIGATIONS

An investigation was made of the closing-in rate of the BeCu strip during heat treatment. The etched tape was heat treated in a 0.562-inch diameter tube and statically annealed for various times up to 45 minutes. The resultant free diameter was then measured. Isotherms for 600°F, 650°F, and 700°F are shown in figures 9, 10, and 11, respectively. A comparison made of the data from a previous contract, represented as Manufacturing Data, shows a reasonable correlation. On the basis of these results, 700°F was selected as the optimum temperature for the salt bath furnace.

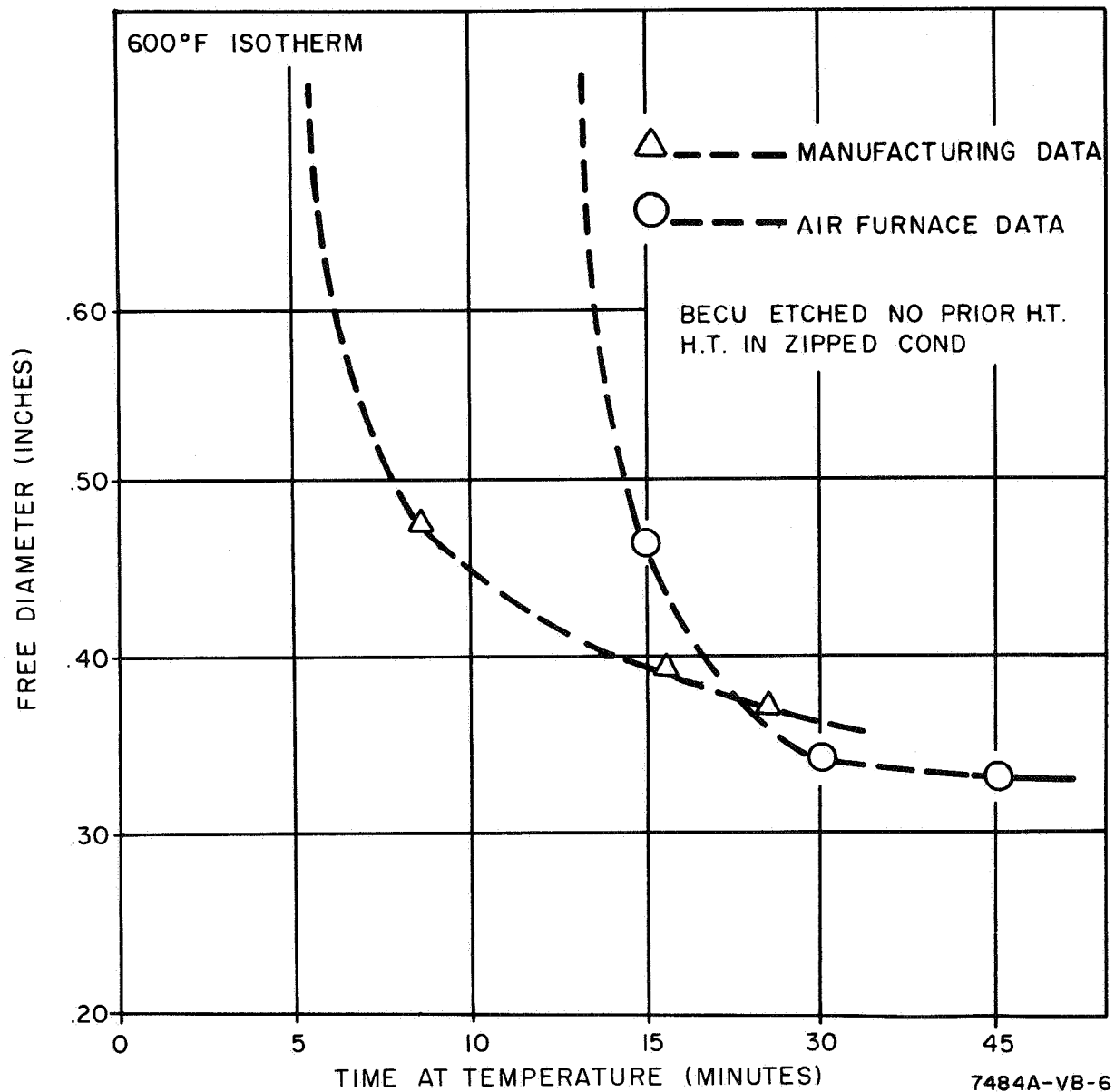


Figure 9. Isotherm for 600°F Comparing Previous Data to Present

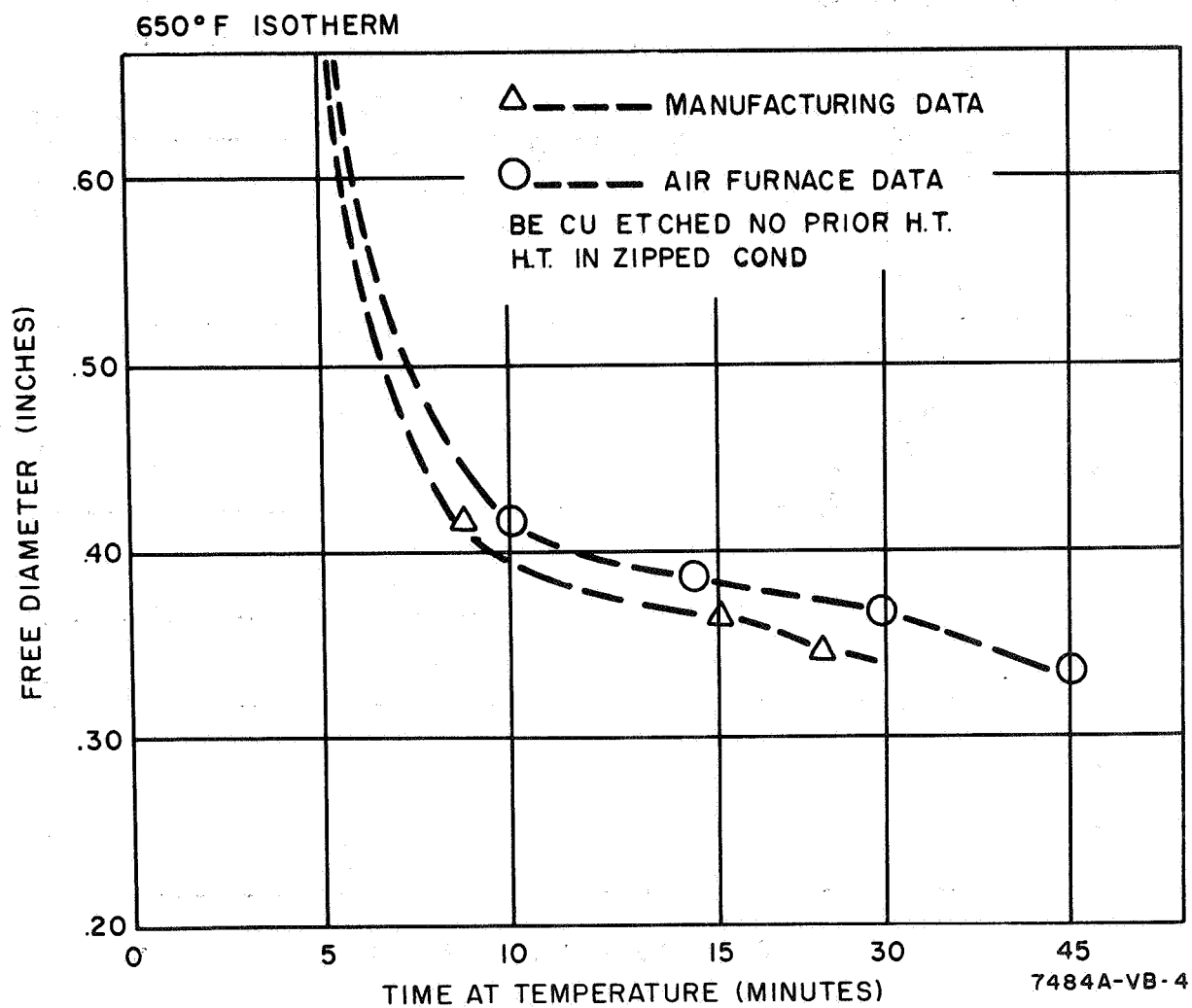


Figure 10. Isotherm for 650°F Comparing Previous Data to Present

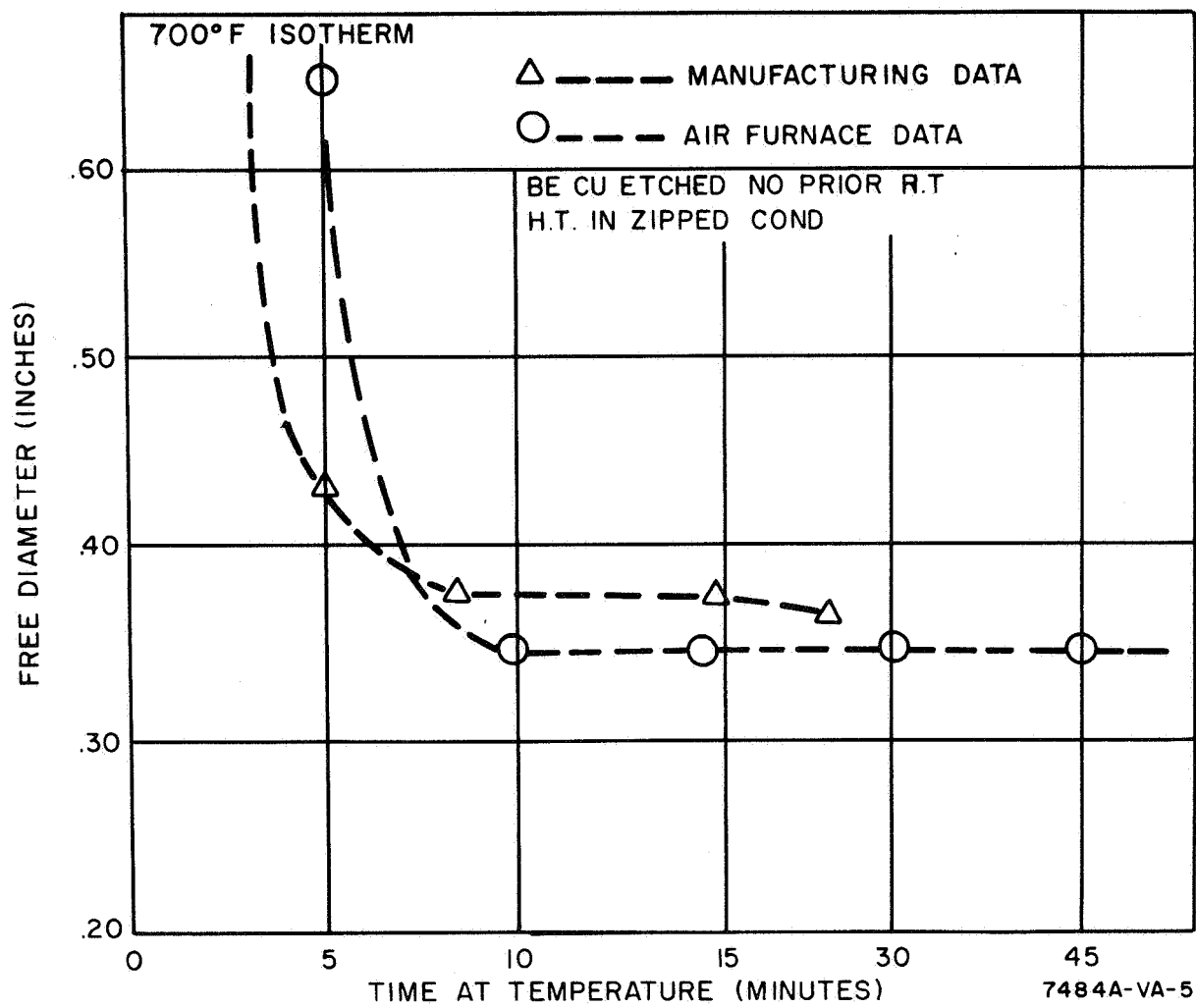


Figure 11. Isotherm for 700°F Comparing Previous Data to Present

## 6. SOLAR ABSORPTANCE ( $\alpha_s$ ) MEASUREMENTS

### 6.1 INTRODUCTION

In order to evaluate the space stability of the boom, a program was established for measuring solar absorptance and reflectance. This section includes a description of the apparatus, method of computation, typical measurements, problems, and proposed solution.

### 6.2 DESCRIPTION OF APPARATUS

Near normal spectral reflectance measurements were made from 0.30 to 1.8 microns on the Cary Spectrophotometer Model 14. This is a double-beam spectro-photometer equipped with an integrating-sphere reflectance attachment. The energy source is projected through an aperture into the spherical cavity which has a diffuse inner surface of high reflectance. Additional ports are cut out of the sphere to accommodate sample and reference specimens. The reflectance of an unknown is obtained by comparison to the energy reflected from a surface of known reflectivity. A schematic of the optical design of the integrating sphere is shown in figure 12.

### 6.3 METHODS OF COMPUTING $\alpha_s$

The solar reflectance and solar absorptance were determined by computation from spectral data using the solar reflectivity computation data sheet shown in table 1. The following describes the computation procedure.

(1) R, % (% Reflectance) is read from spectrograph at the wavelengths shown in column "Sample Pt - microns." These wavelengths represent the center point of the wavelength range shown in "Wavelength - microns." Each range represents approximately 2 percent of the solar spectrum.

(2) The % Reflectance beyond 1.85 microns is estimated by projecting the spectral curve from 1.35 microns.



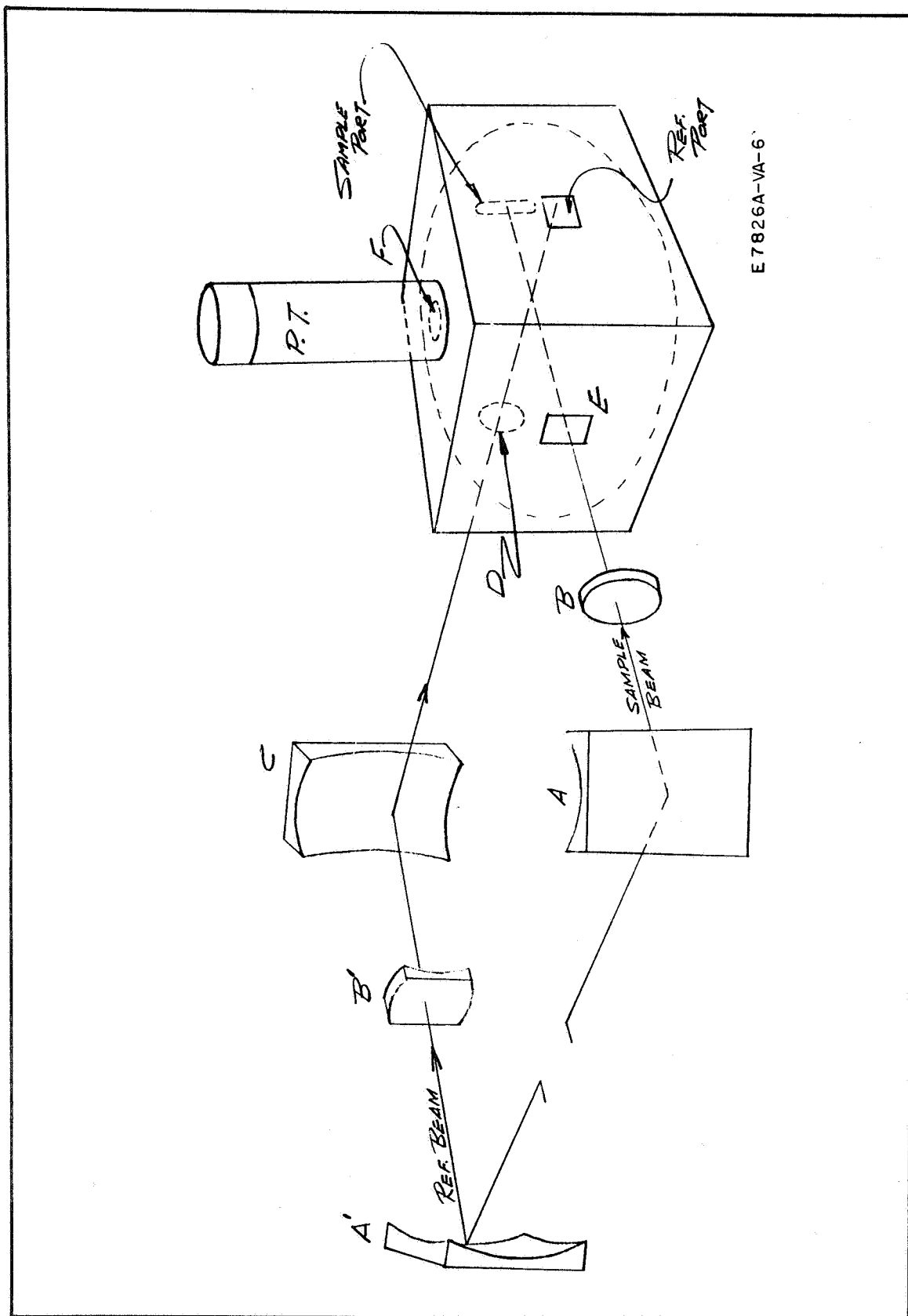


Figure 12. Schematic Diagram of the Optical Design of the Cary Spectrophotometer M14

TABLE 1  
SOLAR REFLECTIVITY COMPUTATION\*

Wave-length (microns)	Irradiance %	Sample Pt. (microns)	R %	Wave-length (microns)	Irradiance %	Sample Pt. (microns)	R %
0.000-0.315	1.97	0.295	_____	0.709-0.728	1.96	0.720	_____
.315-0.342	1.98	0.330	_____	.728-.749	2.06	0.740	_____
.342-.366	2.04	0.355	_____	.749-.770	2.00	0.760	_____
.366-.388	1.96	0.375	_____	.770-.792	1.95	0.780	_____
.388-.407	1.98	0.400	_____	.792-.816	2.05	0.805	_____
.407-.422	2.06	0.415	_____	.816-.841	2.02	0.825	_____
.422-.437	1.93	0.430	_____	.841-.867	1.95	0.855	_____
.437-.451	2.06	0.445	_____	.867-.896	1.98	0.880	_____
.451-.464	2.01	0.460	_____	.896-.925	2.00	0.910	_____
.464-.477	2.02	0.470	_____	.925-.957	1.98	0.940	_____
.477-.490	1.93	0.485	_____	.957-.992	2.00	0.975	_____
.490-.504	2.03	0.495	_____	.992-1.031	2.02	1.010	_____
.504-.518	1.95	0.510	_____	1.031-1.073	2.00	1.050	_____
.518-.533	2.08	0.525	_____	1.073-1.116	2.00	1.095	_____
.533-.547	1.98	0.540	_____	1.116-1.174	1.99	1.15	_____
.547-.562	1.94	0.555	_____	1.174-1.234	2.02	1.20	_____
.562-.576	1.98	0.570	_____	1.234-1.300	1.99	1.25	_____
.576-.590	1.98	0.585	_____	1.300-1.382	2.00	1.35	_____
.590-.605	2.00	0.600	_____	1.382-1.479	2.00	1.45	_____
.605-.621	2.02	0.610	_____	1.479-1.597	2.00	1.55	_____
.621-.638	2.09	0.630	_____	1.597-1.755	2.00	1.65	_____
.638-.655	2.01	0.645	_____	1.755-1.972	2.00	1.85	_____
.655-.672	1.98	0.665	_____	1.972-2.314	2.00	2.10	_____
.672-.690	2.01	0.680	_____	2.314-3.012	2.00	2.60	_____
.690-.709	2.04	0.700	_____	3.012-∞	2.00	4.00	_____

(3)  $R_s$  (solar reflectance) is the percent of the total energy of the sun that could be reflected. It is computed by adding the  $R_s$ , % values and dividing by 50.

$$(4) \% \alpha_s \text{ (solar absorptance)} = 100 - \% R_s$$

#### 6.4 TYPICAL MEASUREMENTS

Some typical measurement of surfaces examined in this study are shown in table 2.

TABLE 2  
TYPICAL  $\% \alpha_s$  MEASUREMENTS

Surface	$\% \alpha_s$
Black Brass	80
"Temescal" Aluminum (3300-Å thick)	9 - 10
(4000-Å thick)	12 - 13
"Catalyst" Aluminum	32 - 33
Ebonol "C" (Copper Oxide)	82 - 83
Beryllium Copper	35

#### 6.5 PROBLEM AREA

A basic problem developed while trying to measure the  $\alpha_s$  of perforated booms. When the perforated, formed boom was flattened so that it could be mounted on the reflectometer, inconsistent data was obtained. The cause of this inconsistency was twofold: (1) the obvious leakage of light around the sampling port because the sample could not be made completely flat; and (2) the inability of the optical design of the instrument to measure perforated surfaces over all wavelengths. As a next step, the specimen was measured backed up with itself so that the surface would appear to be solid. The data was still inconsistent, because it was not possible to eliminate all light leakage around the holes.

In view of the inability to measure a flattened, perforated specimen, the feasibility of measuring a cylindrical specimen was investigated. Initially,

the position of the sample in the port was found to be too critical for repeatability over the entire wavelength region. As a modification of this technique, the position of the sample was adjusted for peak readings at one wavelength. This latter technique, having shown the most promise, was therefore adopted for the following study.

## 6.6 TEST PROCEDURE

Vapor-deposited aluminum on a glass cylinder of the same diameter as the formed boom was placed over the reference port of the Cary Spectrophotometer Model 14. Another cylinder of the same makeup was passed over the sample port and moved about until maximum reflectivity readings were obtained. This was repeated a number of times in order to get an average of peak readings on reflectivity of the vapor-deposited-aluminum standard. A perforated boom sample backed up with itself was measured in the same manner. The reflectivity at one wavelength of the boom was then calculated from the Cary measurements as follows:

$$\frac{\text{Measured Reflectance of the Standard}}{\text{Measured Reflectance of the formed Boom, Backed Up}} = \frac{\text{Reflectivity of Standard (obtained from literature)}}{\text{Computed Reflectance of formed Boom, Backed Up}}$$

## 6.7 RESULTS

Results of measurements using this technique are shown in table 3. The data is considered preliminary in nature; however, the correlation shown was considered reasonable for a qualitative evaluation. Considerably more data would be required before confidence could be given to this approach for  $\alpha_s$  measurements. The technique, however, was considered to have an advantage over the original approach even at this state of investigation.

## 6.8 CONCLUSIONS

Further advancement of this technique is recommended for utilizing the Cary Reflectometer for  $\alpha_s$  measurement of formed booms.

TABLE 3  
REFLECTANCE OF CYLINDRICAL SAMPLES

<u>Measurement</u>	<u>Computed Reflectance of Formed Boom Backed Up</u>	<u>Reflectance of Vapor Deposited Aluminum Standard</u>
#1	85.6%	92.5%
#2	87.5%	84.0%
#3	89.4%	92.0%
#4	84.7%	97.0%
#5	82.9%	95.3%
#6	85.3%	91.6%
#7	86.3%	92.3%
#8	84.6%	95.6%

Measurements made on Cary Spectrophotometer Model 14 at 0.5 microns.

## APPENDIX I

### EVAPORATIVE LOSS OF COPPER OXIDE

The compatibility of copper oxide (Cu O) with the space vacuum environment has been developed by the attached graphs. As can be seen, the compound has a high thermal stability and a very low vapor pressure over the temperature range of interest. This means, as seen from the graphs, an extremely low material loss, indicating the suitability of this material for a space application.

The tables, graphs, and equations were derived from the vapor pressure data of P. Assayag ("The Thermodynamic Properties of Alloys of Copper and Platinum," Ann. Chim., vol. 12, 1955, pp. 637-65 [France]),<sup>9</sup> and the Langmuir equation for evaporative loss rate in a perfect (space) vacuum. The Langmuir equation is:

$$W_T = \frac{P_V}{17.14} \sqrt{\frac{M}{T}} \quad 10 \quad (1)$$

where

- $W_T$  = rate of evaporation, grams/cm<sup>2</sup> - sec at T  
 $P_V$  = vapor pressure of the material, mm Hg at T  
 $M$  = molecular weight of the material  
 $T$  = temperature, °K.

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9 The P. Assayag data was reported in "Handbook of Thermo-physical Properties of Solid Materials," Goldsmith, et al, Volume III, p. 365, Revised Edition, The MacMillan Co., New York, 1961.

10 The Langmuir equation was taken from "Scientific Foundations of Vacuum Technique," Dushman, pp. 18-24, John Wiley & Sons, New York, 1949.

The Assayag data was plotted as  $\log_{10} P_V$  against  $(1/T)$  and the data conformed to a straight line, as expected. From this graph, was derived the following  $P_V - T$  relationship

$$\log_{10} P_V = 10.82 - \frac{1.352 \times 10^4}{T} \quad (2)$$

Combining equations (1) and (2) yields

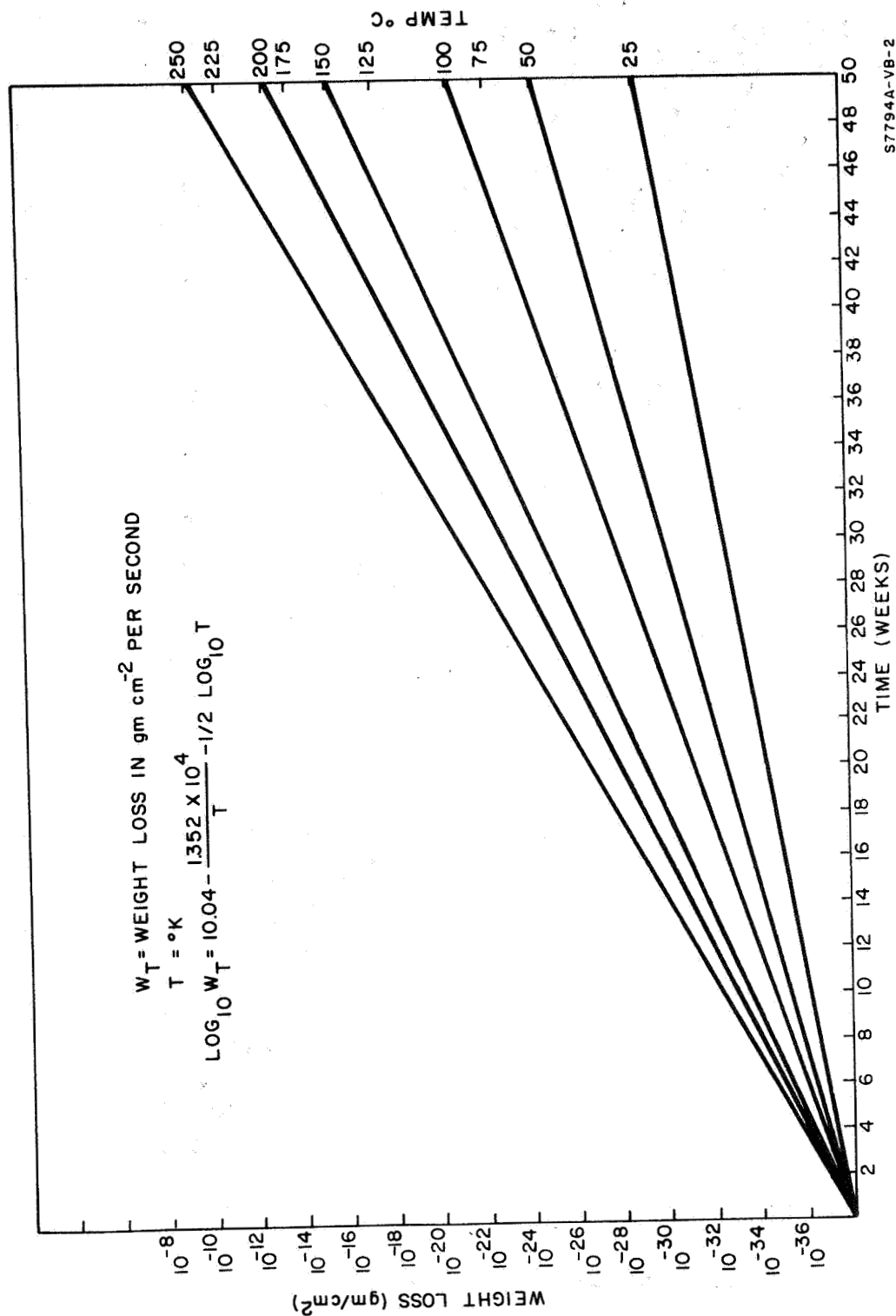
$$\log_{10} W_T = 10.04 - \frac{1.352 \times 10^4}{T} - 1/2 \log_{10} T \quad (3)$$

Equation (3) thus describes the rate of weight loss as a function of temperature.

Dividing equation (3) by the density of the Cu O, and applying the conversion factor to go from centimeters to Angstroms of thickness, the rate change of thickness,  $T_h$  (Angstroms/sec) is

$$\log_{10} T_h = 19.85 - \frac{1.352 \times 10^4}{T} - 1/2 \log_{10} T \quad (4)$$

Equations (3) and (4) are used in the plots of weights loss and thickness change with time at various temperatures as depicted in figures 13 and 14, and table 4.



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Figure 13. Weight Loss of Copper Oxide as a Function of Time



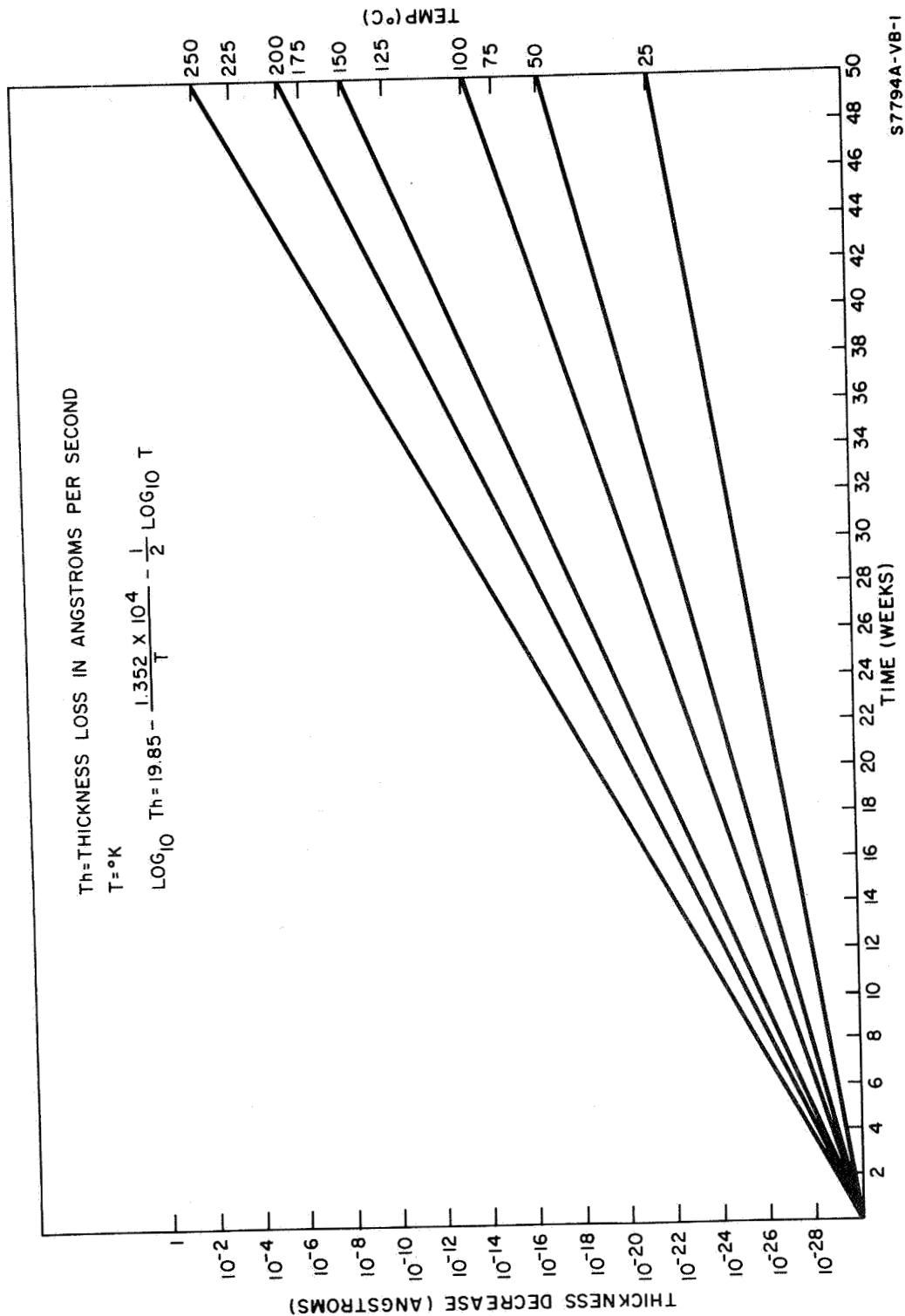


Figure 14. Thickness Decrease of Copper Oxide as a Function of Time

TABLE 4  
DECREASE OF THICKNESS AND WEIGHT LOSS OF COPPER OXIDE  
(Time - 50 Weeks)

Temperature °C	Weight Loss gm cm <sup>-2</sup>	Decrease In Thickness Angstroms
25	$2.1 \times 10^{-29}$	$3.28 \times 10^{-22}$
50	$7.3 \times 10^{-25}$	$1.14 \times 10^{-17}$
75	$7.1 \times 10^{-23}$	$1.11 \times 10^{-15}$
100	$2.7 \times 10^{-21}$	$4.22 \times 10^{-14}$
125	$5.15 \times 10^{-18}$	$8.05 \times 10^{-11}$
150	$4.55 \times 10^{-16}$	$7.1 \times 10^{-9}$
175	$2.78 \times 10^{-14}$	$4.35 \times 10^{-7}$
200	$1.82 \times 10^{-13}$	$2.84 \times 10^{-6}$
225	$3.41 \times 10^{-11}$	$5.33 \times 10^{-4}$
250	$5.80 \times 10^{-10}$	$9.07 \times 10^{-3}$